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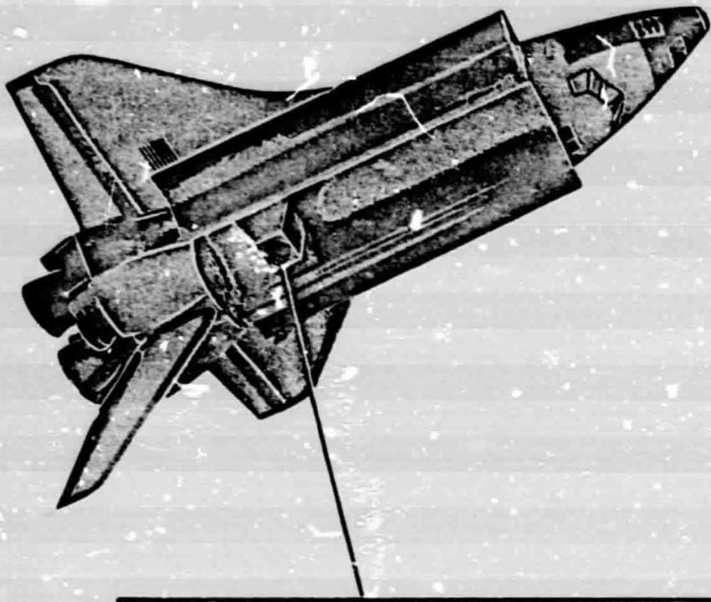

SHUTTLE/ TETHERED SATELLITE SYSTEM DEFINITION STUDY

CONTRACT NAS 8-32853

FINAL STUDY REPORT
(DR MA-05,DPD NO.544)
FEBRUARY 1979

VOLUME I
EXECUTIVE SUMMARY

Prepared for

National Aeronautics and Space Administration
George C. Marshall Space Flight Center
Marshall Space Flight Center, Alabama 35812

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Ball Aerospace Systems Division

BOULDER, COLORADO 80306

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Prepared By
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W. J. Bursnall
Program Manager

FOREWORD

Ball Aerospace Systems Division (BASD), Boulder, Colorado submits this document to the National Aeronautics and Space Administration, George C. Marshall Space Flight Center (MSFC) as partial fulfillment of Data Requirement (DR)MA-05, for the Shuttle/Tethered Satellite System Definition Study, (Contract NAS8-32853). This document, Volume I of the Final Study Report, is the Executive Summary of the study.

The complete final report consists of the following:

- Volume I - Executive Summary
- Volume II - Study Results
  - Part I - Preliminary Design Document
  - Part II - Preliminary Interface Control Document
  - Part III - System Specification
  - Part IV - Program Analysis and Planning Document
  - Part V - Supporting Research and Technology Document
  - Appendix A - BASD Dynamics Analyses
  - Appendix B - Subcontractor Dynamics Analyses
- Volume III - Program Cost Estimates

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INTRODUCTION

The Tethered Satellite System has great prospects for extending orbital operations capability of the Space Transportation System to science, applications, and technology projects not otherwise attainable. The System will be installed in the Shuttle Orbiter and will have the capability to deploy a captive satellite up to 100 km away from the Orbiter. Control and retrieval of the satellite are accomplished by means of a tether line connecting the satellite and the cargo bay mounted equipment in the Orbiter. At low satellite altitudes, the system will permit investigations of a duration that could not be pursued with sounding rockets or free-flying spacecraft. At higher altitudes, the System provides a station-keeping mode for simultaneous measurements at both the satellite and the Orbiter. For all applications, recovery of the satellite promotes a cost-effective utilization of space hardware.

The purpose of the Shuttle/Tethered Satellite System Definition Study was to produce the preliminary design, preliminary specifications, gross program plans, and program cost estimate for a 1982 operational verification flight. This was accomplished by the Ball Aerospace Systems Division (BASD) during a fifteen month effort under contract to the NASA George C. Marshall Space Flight Center (MSFC). The MSFC Phase A and related studies demonstrated the feasibility of the system and served as a starting point for the Phase B definition study. Concurrent work at the University of California-Los Angeles (UCLA), also supported by MSFC, provided input to the Phase B study on science requirements of a magnetometer experiment payload for the satellite. During the course of the definition study, other sectors of the scientific community identified a variety of user interests in the system. These interests were brought into focus at the Workshop on the Uses of a Tethered Satellite System conducted by the University of Alabama in Huntsville for MSFC. Although the results of this Workshop were not specifically incorporated in the definition study, they have provided guidance for the formulation of tasks extending beyond the present scope of effort.

The summation of the work accomplished during the study is presented in a three-volume Final Report. This document is Volume I, Executive Summary, and contains an overview of the total program results, a summary technical description of the TSS, a review of the major programmatic aspects of Phase C/D, and a discussion of the accommodations available for potential operational users of the system. Detailed results and conclusions are presented in the five parts and two appendices of Volume II, Study Results. The Phase C/D costing and Work Breakdown Structure are presented in Volume III, Program Cost Estimates.

STUDY APPROACH AND GUIDELINES

The Shuttle/Tethered Satellite System Phase B study has been directed primarily toward the definition of a program for flight verification of the system. The goal of the study was to define the preferred means for implementing the tethered satellite concept so that it would be:

(1) A safe shuttle passenger
(2) A compatible facility for a wide range of potential users and
(3) A cost-effective, reusable addition to the Space Transportation System.

STUDY OBJECTIVES

PRODUCE THE PRELIMINARY DESIGN, PRELIMINARY SPECIFICATIONS, GROSS PROGRAM PLANS, AND PROGRAM COST ESTIMATE FOR THE 1982 OPERATIONAL VERIFICATION FLIGHT.

The primary guidelines set for the study were directed toward accomplishment of the first flight at low cost while retaining flexibility to accommodate potential users. The only science payload identified at the start of the study was a magnetometer. The primary satellite payload was to be the Engineering Instrument Package (EIP) required for verification of the system operation.

Dr. Paul Coleman and Dr. Malcolm McLeod of UCLA, under a grant from NASA, developed magnetometer experiment requirements for guidance of the Phase B contractors. In May 1978, NASA also sponsored a tethered satellite users Workshop which identified a wide range of experiments suitable for TSS. The requirements for these experiments were not specifically incorporated in the Phase B study but will form the basis for extended investigations of tethered satellite concepts.

Although the early parametric analyses of the satellite considered satellite masses up to 500 kg. it became apparent that the larger satellites would be in conflict with the low-cost guideline. The majority of the design work, therefore, concentrated on the lower end of the mass range.

SYSTEM GUIDELINES

MISSION: ORBITER AT 220 KM; SATELLITE AT 120 KM
36-HOUR VERIFICATION FLIGHT
6.5-DAY MISSION CAPABILITY
SEPTEMBER 1982 LAUNCH

SATELLITE MASS: MINIMUM 200 KG; UP TO 500 KG

SYSTEM MASS AND SIZE: COMPATIBLE WITH ORBITER/SPACELAB

SYSTEM DESIGN AND OPERATION: SAFETY IS PARAMOUNT

LOW COST: PROTOFLIGHT APPROACH
PROVEN CONCEPTS AND COMPONENTS

FLEXIBILITY TO ACCOMMODATE POTENTIAL USERS

Within the total work defined, the following were the technical ares of concentration:

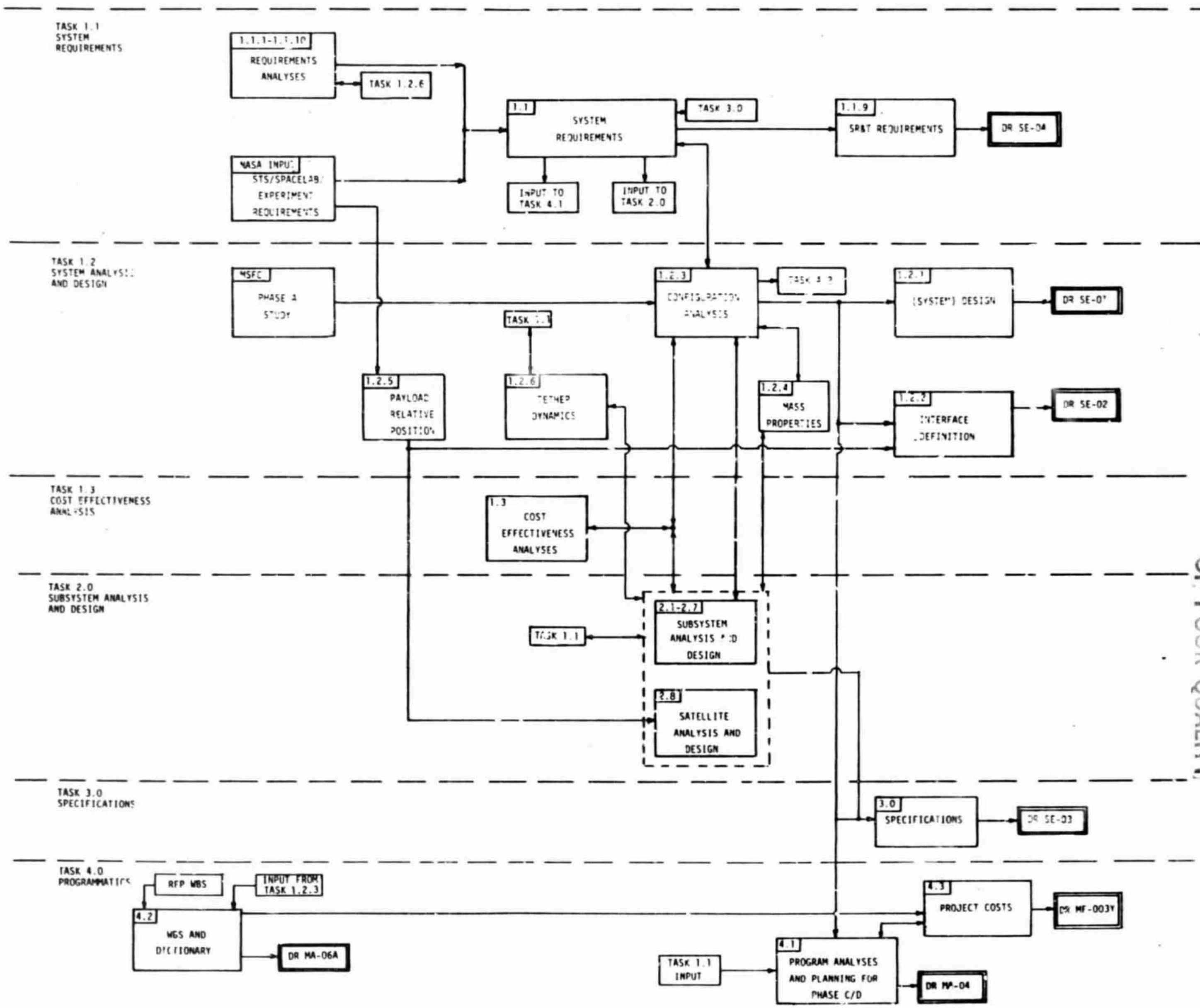
- Tether Dynamics
- Tether Handling
- Kevlar Properties
- Satellite Thermal Protection
- Satellite Position Locations
- Science Accommodation Flexibility

At the outset of the study, it was obvious that the primary factor influencing the realization of the study goal was the control of tether dynamics. The dynamic behavior drives the system and subsystem requirements and is a primary consideration in the integration of the system with the Orbiter and its other payloads. The mechanical equipment required to stow, deploy, and retrieve the tether line is unique in space flight. The Dupont material, Kevlar, has a number of unique properties which made it appear, initially, as ideal for the tethered satellite application. Satellite thermal protection, after dynamics, was a primary concern at the beginning of the study. Satellite position information was a key element in the success of the magnetometer experiment. The ability to carry a variety of experiments in the satellite will promote user interest and support.

Throughout the study, the concept of flexibility to accommodate not only different science but, also different tethers and a range of operating conditions has been maintained.

BASD was supported in the dynamics portion of the study by two subcontractors. WHF and Associates conducted analyses to assess the effects of tether flexibility, evaluate the effectiveness of alternate control laws, and study "steady-state" control operations. Complimentary work on control law alternatives was accomplished at Howard University under the direction of one of the WHF principals.

STUDY TASK FLOW CHART



Two Independent Research and Development tasks were undertaken by BASD in parallel with the contracted study. Results of these tasks will be discussed in the appropriate sections following.

One task was concerned with the physical properties of candidate tether materials. In this task, tensile strength of Kevlar cordage was measured after abrasion and ultraviolet radiation tests. In addition, a technique was developed to remove Dupont proprietary lubrication (not space compatible) from the cordage. Test specimens were then relubricated.

TETHERED SATELLITE SYSTEM ELEMENTS

SATELLITE
(EVERYTHING AT THE END OF THE TETHER)

SATELLITE DEPLOYER
(EVERYTHING IN THE ORBITER BAY)

FLIGHT SUPPORT EQUIPMENT
(EVERYTHING IN THE AFT FLIGHT DECK)

GROUND SUPPORT EQUIPMENT

SOFTWARE

1-9 - to - 1-12

SYSTEM DYNAMICS

Extensive computer-simulation studies of satellite dynamics and control have been performed for the mission phases of steady-state operations at altitude, deployment, and retrieval.

When the satellite is suspended from the orbiter by the tether, it pendulates or librates, with very little damping, depending on initial velocities, excitation from the varying atmospheric drag etc.

The libration motion can be damped by varying the tension in the tether (and consequently its length) according to a "control law", which enables the satellite to be retrieved, deployed or the satellite altitude to be controlled without introducing excessive libration, and in some cases reducing any libration motion already present.

Of the possible "control laws" which might be used, one has been selected which involves, in addition to a length-time command profile, only three feedback parameters, namely:

(1) Tether length

(2) Rate of change in tether length and

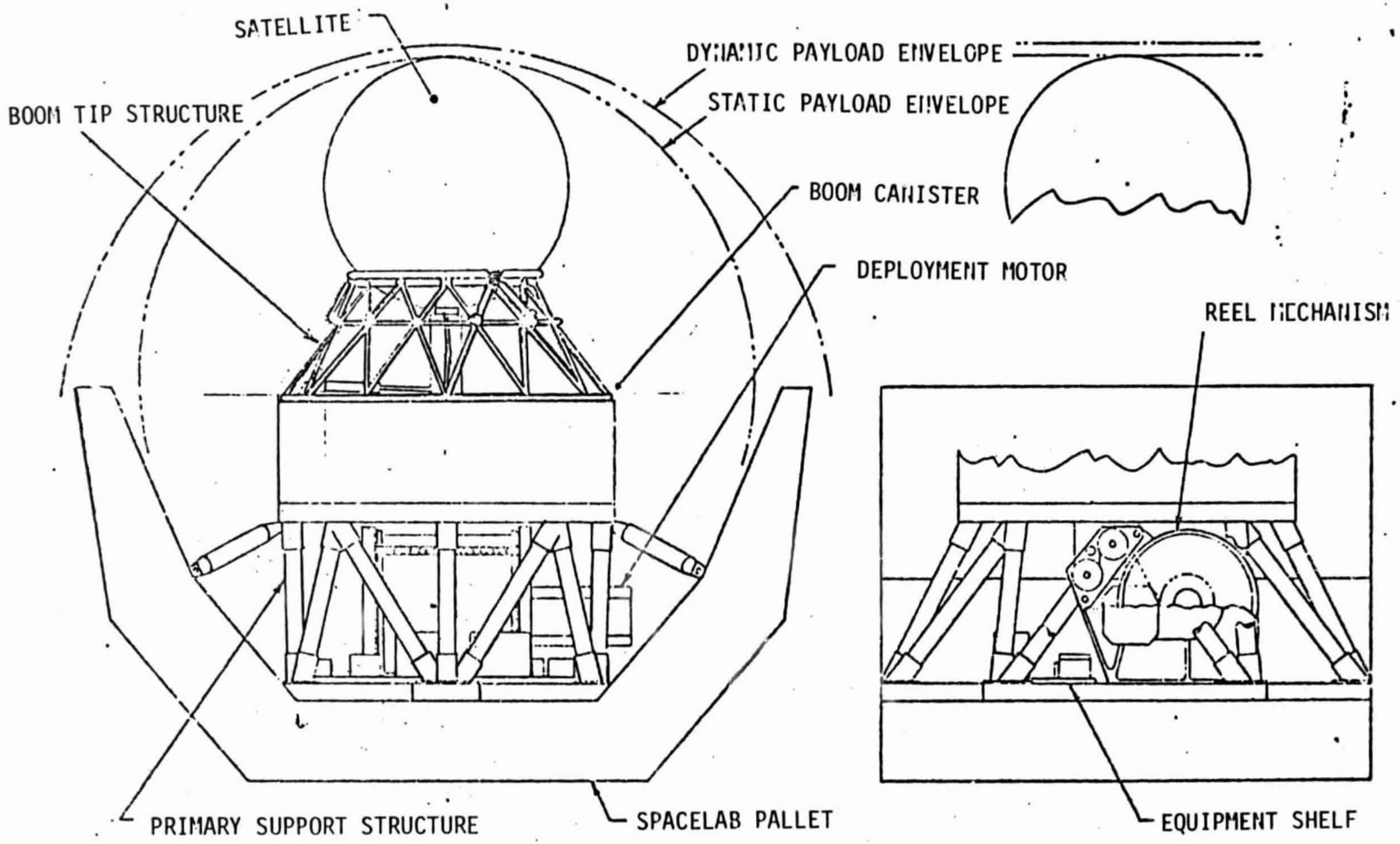
(3) Tether tension, as measured at the Orbiter

SYSTEM DESCRIPTION

A satellite 1.4 meters in diameter, together with a boom and reeling mechanism are compatible with a standard spacelab pallet and the static payload envelope.

The boom, 175 cm. in diameter, is required to withstand the moments arising at various orbiter attitudes. All associated deployer components except the tracking and data antenna are located on an equipment shelf in the base of the deployer assembly.

GENERAL ARRANGEMENT



Nearly all equipment peculiar to the tethered satellite is located on the spacelab pallet. This includes the reeling mecahnism, boom, capture and release mechanisms, energy storage, the tether control electronics, and tracking and communications equipment.

The only other TSS-peculiar equipment is a small deployment control and caution and warn panel (flight support unit) located on the aft flight deck.

The Spacelab Data Display System (DDS) located on the aft flight deck is used to monitor and control the deployer.

The orbiter Data Display Unit (DDU),also on the aft flight deck,is used to monitor and control the satellite.

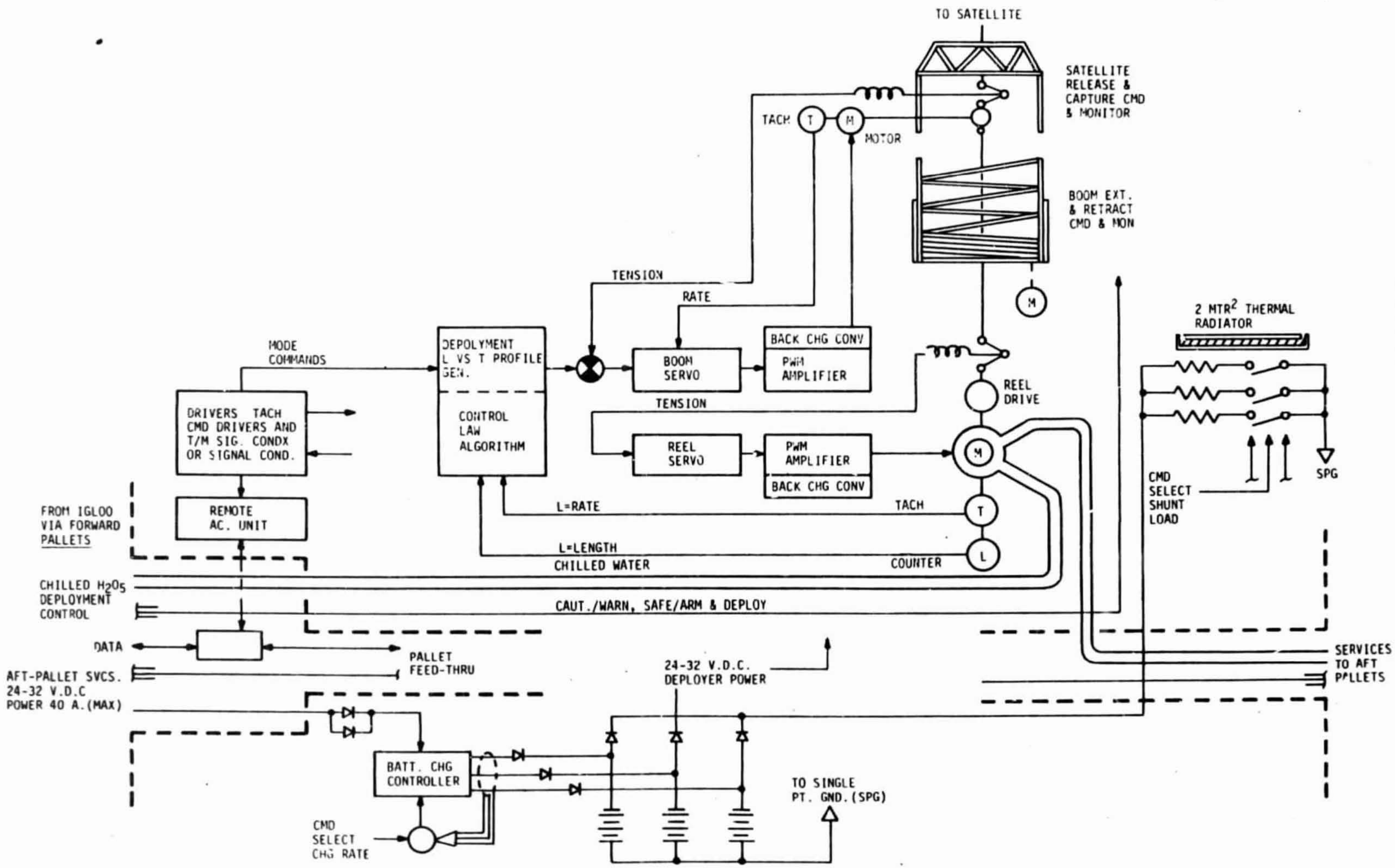
Support computer functions are required of both the orbiter General-Purpose Computer (Avionics Bay) and the Experiment Computer located in the Spacelab Igloo. Functions commonly encountered in space craft flight operations are relegated to these computers. Specialized computations, such as feed back control, are performed by the TSS control Processor located on the pallet.

Tether Control Servo Amplifiers

- The reel servo motor runs in response to reel tension measurements and winding velocity feed back signals.
- The only other inputs to the reel servo are mode commands from the deployer control processor, which initiate winding, payout, start and stop modes.
- The boom motor servo receives, in addition to rate and tension feed back signals at the tether exit guide and various mode commands, also a tension command signal from the control processor, of such a magnitude to achieve motion of the tether according to a predetermined length profile.
- Control commands and monitoring for the satellite and boom deployment are hardwired directly from the TSS flight support panel on the aft flight deck to the caging and release assemblies on the boom.
- Services to other pallets in the spacelab pallet train, including the chilled water loop from the reel motor cooling jacket, pass thru the TSS pallet assembly via standard pallet interface fittings.

3-5, 3-6, 3-7

TETHERED SATELLITE PALLET-MOUNTED DEPLOYER

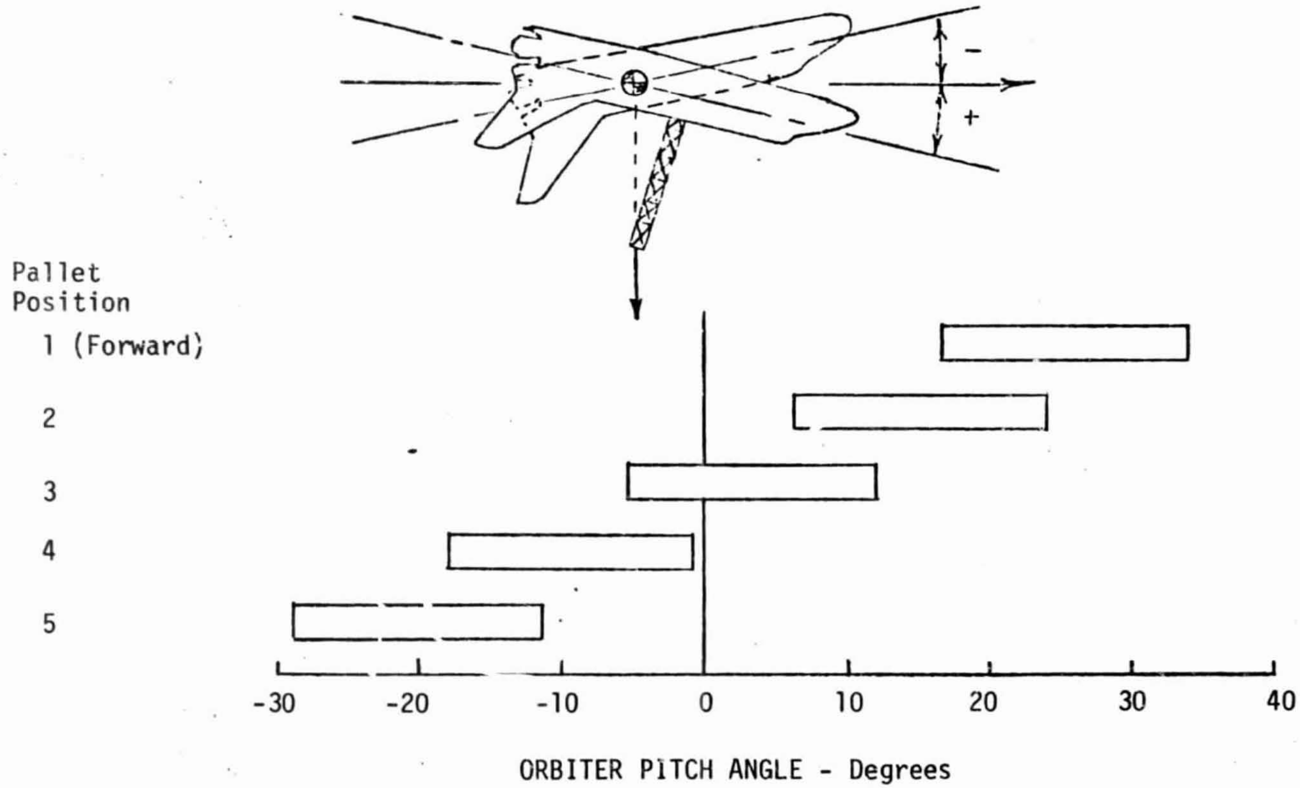


3-9

Tether Reeling Mechanism

- Tether tension is controlled by two servo motors. A relatively large motor drives the reel and level winding mechanism, automatically maintaining a tension at the reel suitable for proper winding and unwinding.
- A second motor, located at the boom tip, controls the tension in the tether connected to the satellite, by the action of a pinch wheel mechanism.
- Both motor drives are equipped with rate tachometers and tension measuring instrumentation which supplies signals to the respective drive servos, and braking devices for holding the tether when stopped.

ORBITER FLIGHT ATTITUDE



3-11 to 3-14

A typical verification mission profile involves operation at several different satellite altitudes and tether lengths.

The orbit will be operated principally in the drift-free altitude mode (pitch & roll) so that little fuel is consumed in maintaining attitude control. The orbiter will seek an attitude such that the tether line of force passes through its center of mass.

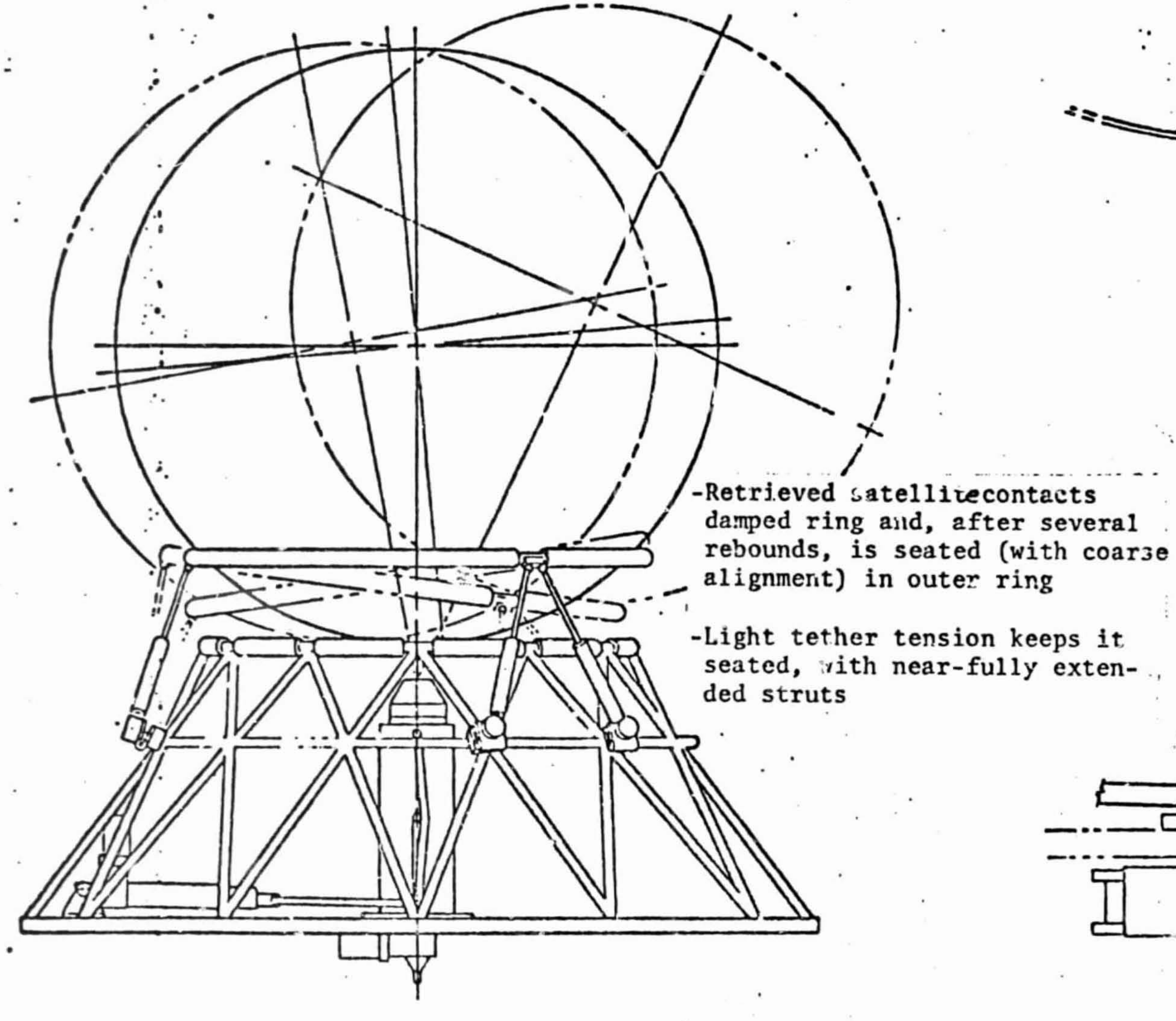
Altitude make-up maneuvers will be made by the orbiter every few hours, when the satellite is flying at altitudes below about 140 km. These maneuvers require attitudes which introduce substantial moments due to tether tension, but the time duration is relatively short.

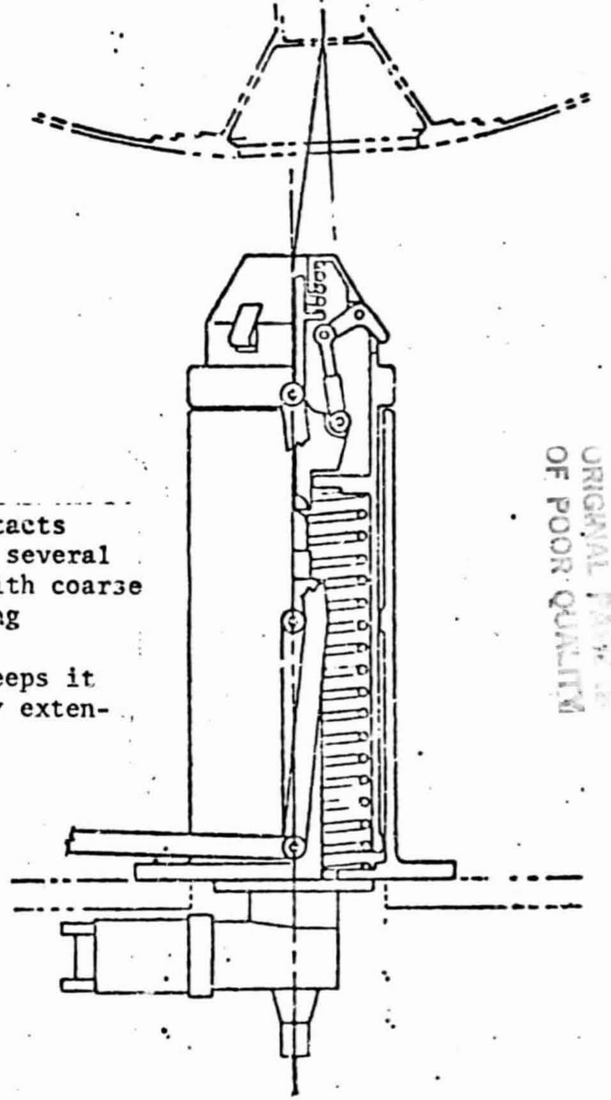
Tether tension is roughly proportional to the length payed out and reaches a magnitude of 125 -160 neutons (30 to 40 lbs) for a satellite mass of 350 kg.

The largest component of atmospheric drag, and also the main contribution to Orbiter fuel usage, is that of the tether. Even the tether drag is fairly small until its lower end is at an altitude of less than 140 km, at which it begins to increase rapidly. At 120 km altitude, the satellite drag is only about 1/10 that of the tether.

About 1250 kg of orbiter fuel is required for a mission involving satellite altitude of 120 km for a duration of 15 hours.

ACTION OF DOCKING MECHANISM
- INTERVEHICLE LOAD DAMPING AND SATELLITE COARSE ALIGNMENT -





3-17, & 3-18

Selection of a tether line material will be a mission-peculiar requirement in the operational phase of TSS utilization. Potential applications of the TSS indicate the need for insulating, conducting, or insulated-conducting tethers, depending on the particular experiments to be performed. Experiment operations also call for different satellite altitudes and tether lengths.

Several other factors must be considered in tether material selection. A high specific tensile strength is desired to minimize tether mass and diameter. However, the specific T.S. must take into account strength degradation factors such as abrasion, high temperatures, UV radiation, and micrometeoroid impact. The effects of abrasion, temperature, and UV radiation on Kevlar were determined during BASD's IR&D tests. These combined effects could reduce tether strength to as low as 25% of the nominal value. However, a 1.5mm diameter Kevlar tether provides a strength margin of 8-10 for projected verification mission strength requirements.

An area requiring further investigation before final tether selection is that of the techniques for achieving reliable (low strength-degradation) terminations and splices. For the long 100 km tethers, procurement economies can be realized by splicing sections together rather than specifiying a single flawless line. For metallic tethers, in particular, 100 km exceeds single-run production capability.

SPECIFIC TENSILE STRENGTH

	SPECIFIC TENSILE STRENGTH (IN.)	
MATERIAL	ROOM TEMP	500°K*
KEVLAR	7.6×10^6	4.8×10^6
S-GLASS	5.6	5.0
STEEL	1.8	1.6
GRAPHITE (HT)	6.5	5.8

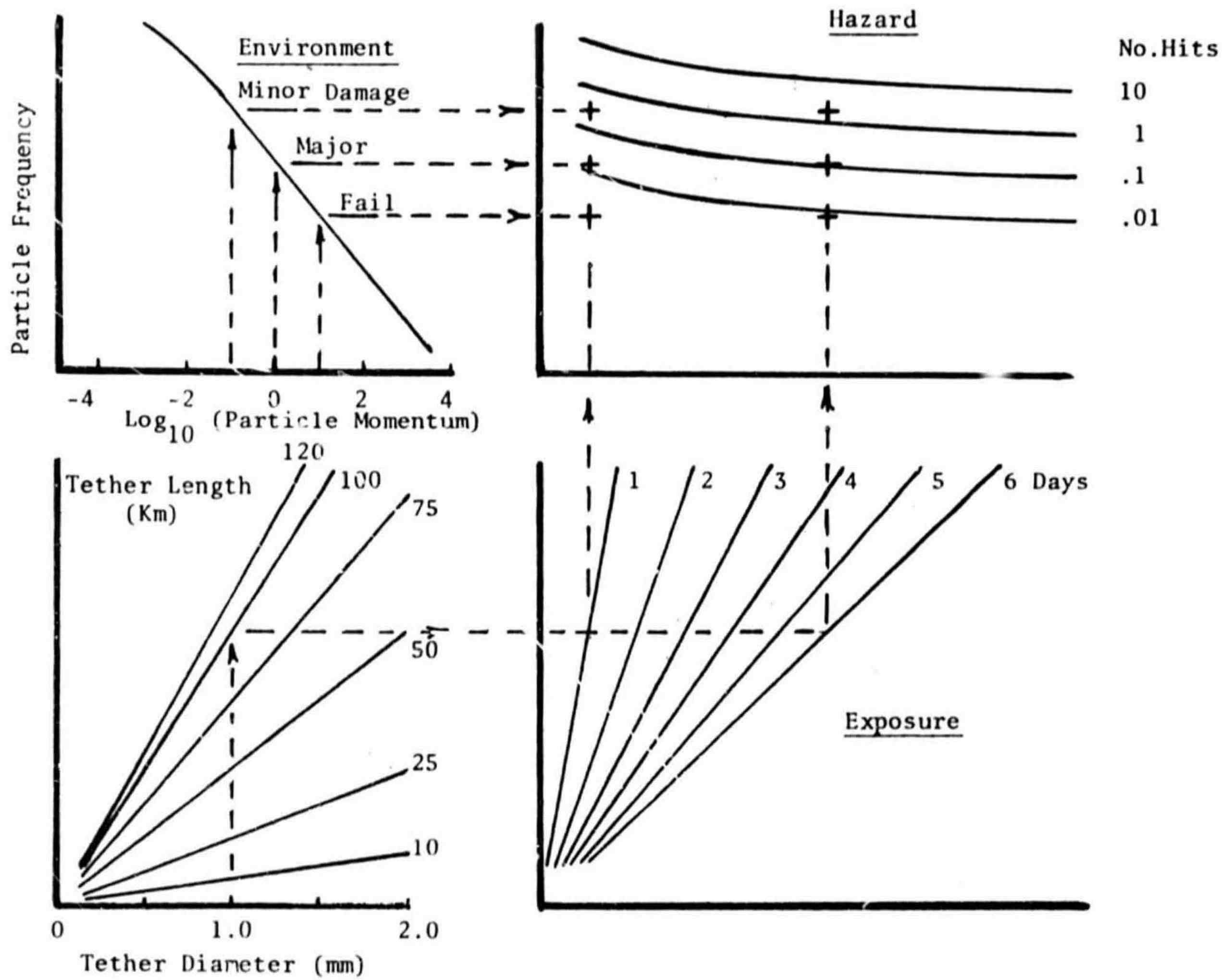
* FOR 100 HOUR EXPOSURE

Test of hypervelocity-particle impacts on several tether materials were conducted at NASA/Langley for MMC. Of the three materials tested,Kevlar, multi-strand steel, and single strand steel,none showed clear superiority in the hypervelocity inpact tests.

The parameter recommended by Langley to scale test results to natural environmental conditions was particle momentum. For a 1-2 day verification mission, the probability of a failure-producing hit is about .005. A data base is not yet available for assessing the cumulative effects of minor-damage impacts.

A comprehensive test and analysis program should be undertaken to permit better evaluation of the micro-meteorioid hazard question. Resolution is also required on the damage parameter to be used in scaling test results. The SAO studies have used particle kinetic energy as a criterion in their analysis which indicate an acceptable level of tether survivability.

MICROMETEOROID HAZARD



It is apparent that a single tether material or construction will not satisfy the requirements of all potential users. The deployer system preliminary design presented herein has the flexibility to incorate a range of tether diameters, lengths, and materials. As the program progresses and more precise selection criteria are developed, tether material alternatives can be more readily compared.

SDS THERMAL CONTROL

- MAJOR SOURCE OF HEAT GENERATED AS ELECTRICAL POWER WHEN SATELLITE IS BEING DEPLOYED
  - REJECT THROUGH TSS-DEDICATED RADIATOR
  - 1.5 SQUARE METER KAPTON STRIP HEATER
- REEL DRIVE MOTOR HEAT DUE TO LOSSES
  - DIRECT RADIATION LIMITED BY INSTALLED LOCATION
  - ACTIVE COOLING WITH SPACELAB "EXPERIMENT HEAT EXCHANGER" (INTERFACES TBD PER SPAH)
- SHELF-MOUNTED EQUIPMENT AND REEL MOTOR RADIATIVE DISSIPATION

3-25, 3-26

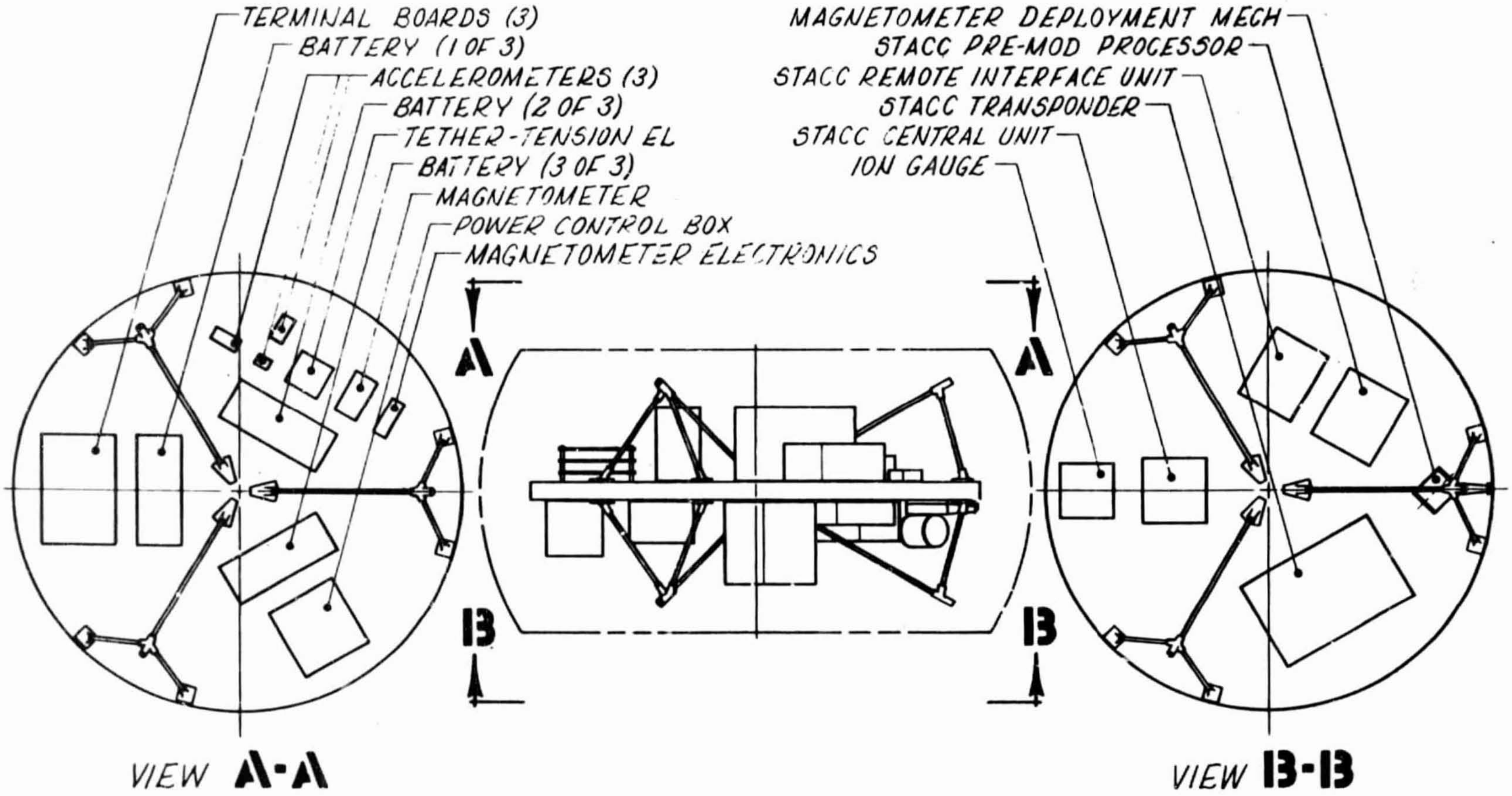
The 4MHz noise bandwidth of the orbiter payload interogator receiver is a factor of 250 as great as the anticipated requirement for the TSS. To achieve the same noise figure, a proportionally more powerful transmitter is required in the tethered satellite.

If it is impossible to reduce the receiver bandwidth for the TSS mission, then it may be necessary to provide an independent, pallet-mounted TSS communication system.

Further study of the communications system alternatives is recommended during any future study activity.

TSS SPACECRAFT CONCEPTUAL DESIGN

SELECTED CONFIGURATION - INTERNAL ARRANGEMENT



3-29 — 3a - 3-38

Electrical Energy for the satellite is provided by 2-30 amp the high density primary batteries. In addition to power required for satellite housekeeping functions, 300 watt-hours of energy is available for experiments or instrumentation such as the verification mission engineering instrumentation complement.

The command receiver is permanently connected to the continuous supply bus. All other equipment including the transmitter/backing beacon is turned on by issuing commands from the orbiter.

The ion gauge, depending on the type selected, can provide course attitude data relative to the velocity vector of the spacecraft, or possibly data on atmospheric composition.

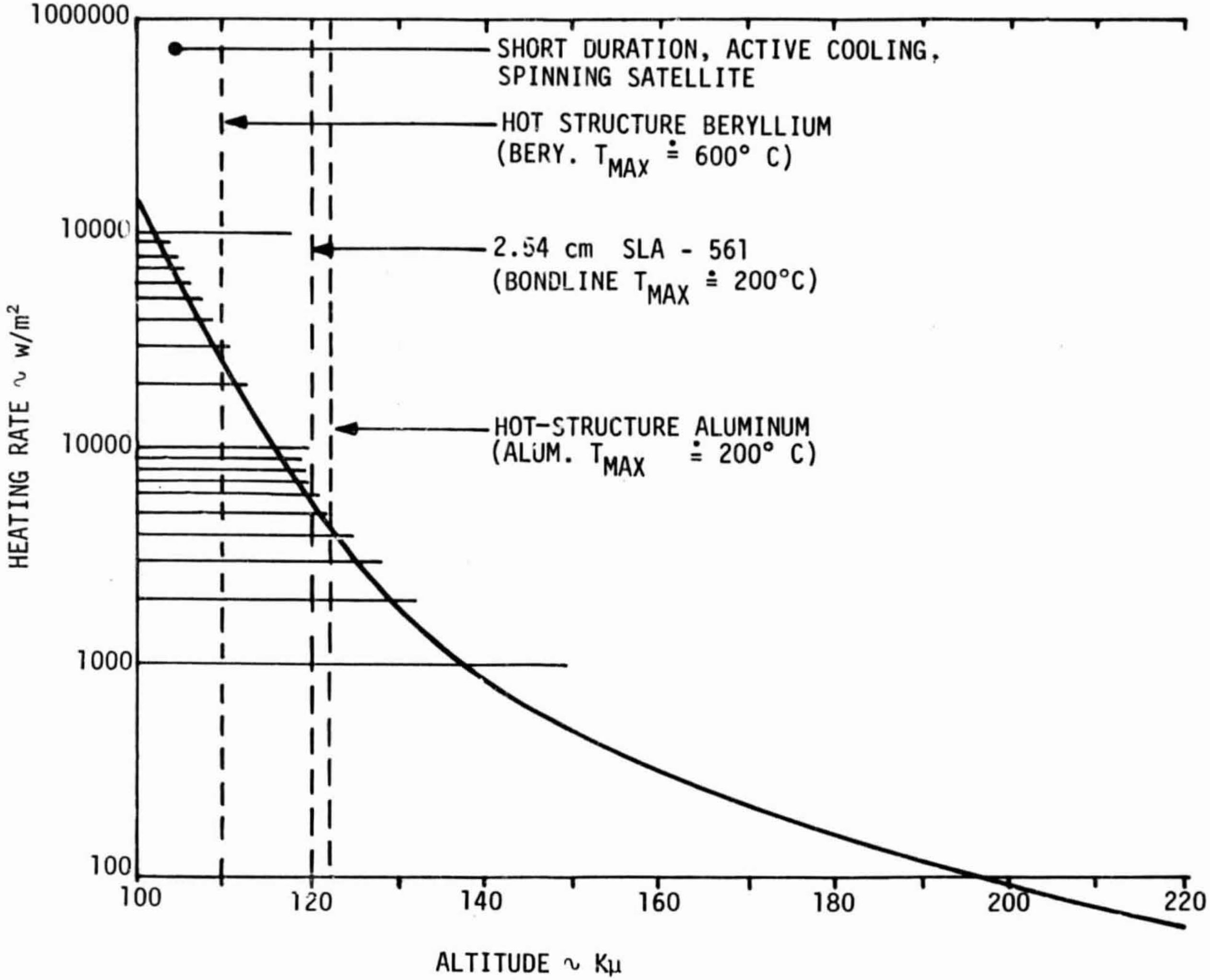
Tether tension and departure angle are measured at the point of tether attachment, and spacecraft attitude is determined by comparing the outputs from a 3-axis, flux-gate magnetometer, with known components of the earths magnetic field.

Temperature monitors measure local temperatures of the spacecraft structure and components.

The deployable/retractable stabilization boom is equipped with a lossy hinge which absorbs energy as the aerodynamic moment causes motion of the vane relative to the satellite body.

Tracking and data antennas, for communication with the orbiter,are mounted flush with the shell surface, on the upper side of the satellite.

THERMAL PROTECTION SYSTEM (TPS) CONCEPTS FOR VARIOUS ALTITUDES



41-42

For the first TSS mission, a "hot" aluminum structure has been adapted. Isolation of the satellite interior from the external heat load is accomplished with installation of 10-layer MLI on the aeroshell interior. Further, fiberglass fittings are used for attachment of equipment-shelf struts to the shell. The combination of a phase-change material and aft-facing radiator provide flexibility for accommodation of other than nominal mission profiles. With a 70W ($0.24m^2$) radiator and 10 kg. of Octadecone, at total time at altitude of 32.5 hours will be sustained. For longer, low-altitude mission, modifications to the radiator size and mass of Octadecane can be accomplished without major changes to satellite configuration. Both the radiator and satellite shell exterior are coated with a high emissivity porcelain-enamel material.

THERMAL PROTECTION APPROACH

- ISOLATED "HOT" SHELL-MLI INTERIOR; PORCELAIN-ENAMEL EXTERIOR

- PHASE CHANGE MATERIAL-OCTADECANE

MELT POINT	28.2°C
HEAT OF FUSION	57.65 W-HR/KG
SPECIFIC HEAT	0.59 W-HR/KG-°C
DENSITY	845.8 KG/M^3 (SOLID)
	776.9 KG/M^3 (LIQUID)

- THERMAL RADIATOR

  PORCELAIN-ENAMEL SURFACE

TSS SPACECRAFT CONCEPTUAL DESIGN

SELECTED CONFIGURATION - WEIGHT SUMMARY

SUBSYSTEM	WEIGHT (KG)
STRUCTURES AND MECHANISMS	185.5
COMMAND AND DATA HANDLING	23.0
ATTITUDE CONTROL AND DETERMINATION	3.5
ELECTRICAL POWER	48.3
ENGINEERING INSTRUMENT PACKAGE	9.6
THERMAL CONTROL	37.8
PAYLOAD EXPERIMENTS (SCIENCE)	1.2
TOTAL	308.9

NOTE: ALL WEIGHT ESTIMATES INCLUDE 15% CONTINGENCY

The Tethered Satellite as configured for the verification mission will accommodate basic engineering instrumentation to evaluate the performance and behavior of the system to fly for an extended length of time at an attitude of 120 km (100 km tether).

Several features of the verification mission spacecraft are also compatable with particular kinds of scientific experimentation. Also some excess capacity exists with respect to weight capability, data capacity, and available electrical power, which could be used for scientific instrumentation.

The accompanying tables enumerate these basic features and capabilities, which could be employed without major modification to the system.

BASIC EXPERIMENT ACCOMMODATION CAPABILITY USING
BASELINE (VERIFICATION MISSION) SYSTEM CONFIGURATION

- ON-STATION ALTITUDE - 120 KM MIN - DURATION OF 20 HRS.
  115 KM - SHORT DURATION EXCURSIONS - ON EXPERIMENTAL BASIS.
- EXPERIMENT/SATELLITE MONITORING & CONTROL - REAL TIME FROM ORBITER; AS AVAILABLE FROM POCC VIA STDN/TDRSS.
- SATELLITE ATTITUDE
  - CONTROL LIMITS: ± 20° RELATIVE TO VELOCITY VECTOR AND NADIR
  - SLEW RATES MAX: 10°/MINUTE
- SATELLITE ATTITUDE DETERMINATION ACCURACY: ± 2° RELATIVE TO EARTH COORDINATES

BASIC EXPERIMENT ACCOMMODATION CAPABILITY - USING BASELINE (VERIFICATION MISSION) SYSTEM CONFIGURATION (CONT'D.)

• DATA HANDLING		
- PRIME DATA	- SAMPLING INTERVAL (WORD)	1 MILLISEC
	- PRECISION (WORD LENGTH)	8 BITS
- HOUSEKEEPING	- ANALOG/DIGITAL INPUT	
	- SAMPLING INTERVAL (MIN.)	16.4 SEC
	- NO. CHANNELS	16
- STATUS (MODE) MONITORS		
	- SINGLE-BIT INDICATORS	32
• EXPERIMENT ELECTRICAL ENERGY 24-32 V.D.C.		300 WATT.-HOURS
• EXPERIMENT WEIGHT		10 KG.
• EXPERIMENT SIZE-APPROX.		0.1 MTR^3

BASIC EXPERIMENT ACCOMMODATION CAPABILITY - USING BASELINE (VERIFICATION MISSION) SYSTEM CONFIGURATION (CONT'D.)

- SATELLITE POSITION DETERMINATION
  - GEOGRAPHIC LOCATION ± 5 KM
  - ALTITUDE ± 3 KM
- SATELLITE LOCATION DETERMINATION
  - RELATIVE TO ORBITER - ANGULAR 3°
  - - DISTANCE 2 KM
- EXPERIMENT COMMANDS AVAILABLE
  - DISCRETE (ON-OFF) 16
  - DIGITAL (MAGNITUDE 12-BITS) 4
  - STORED ON ORBITER

Accommodation of experiment requirements which exceed those inherent in the basic verification-mission spacecraft will have varying degrees of impact on the spacecraft subsystems.

Further assessment of these impacts will involve definition of specific needs for individual experiments, and an examination of the functional requirements at both the system and subsystem levels.

SCIENCE ACCOMMODATION IMPACTS

	SYST./SUBSYSTEM DESIGN AREAS IMPACTED											
	SATELLITE						DEPLOYER					
SCIENCE CAT/EXP TYPE	BASIC STR. DES	DEPL/EJECT. MECH.	AERODYN. DESIGN	THERMAL CONTROL	ATT. CONT. & DETER	INSTRUMENTATION	REELING MECHANISM	ELECT. TETH ATTACH	CAPTURE MECHANISM	ATTACH/REL. MECH.	TETHER MATERIAL DEV./EVAL.
I. Geological Magnetic											
1 G-G Dumbbell						TBD					
II. Atmospheric											
2 Atomic-Mol. Fluorescence	Med		Med	Med		Med			Small	Small	
3 Mass spectrometry	Small		Small	Small						Large	
3A Multiple Satellites	Small		Small	Small					Large		Med
4 Atmos. Electrodyn							Small	Small			
5 Chem Releases	Med	Large		Med	Med						
6 Aerodynamic Effects	Med	Med	Large	Large	Med	Med			Med	Med	
6A Lifting Body	Large		Large	Large					Large	Large	
III. Electrodyn Plasma											
7 Electro Dyn.-100Km Tether							Med	Med			Large
7A -20 Km Tether							Small	Med			Med
8 Interact W/Ionosphere							Small	Med			Med
9 Large Body Plasma Flow	Large	Large	Large	Med		Large			Med*	Med*	

FLIGHT SUPPORT EQUIPMENT

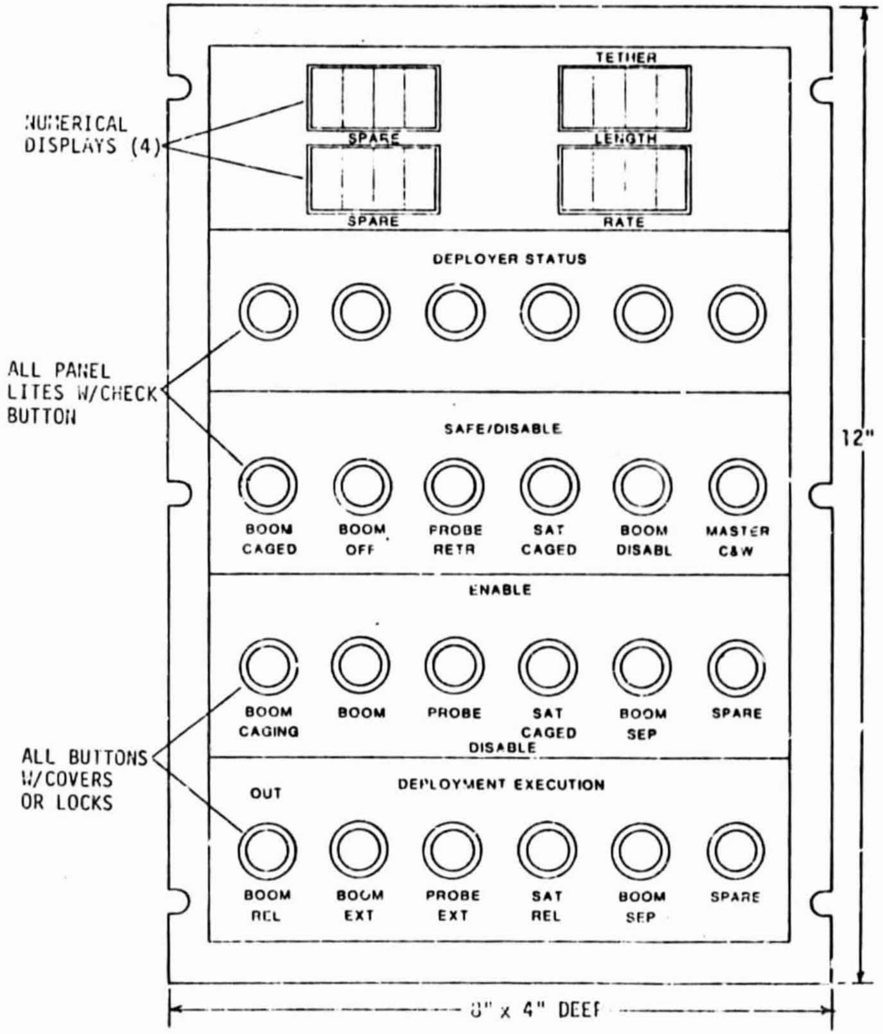
The TSS Control Panel (Flight Support Equipment), located on the aft flight deck, contains monitoring lights and execution switches for safeing, enabling, and execution of deployment functions.

This part of the deployer control is hardwired directly to tell-tale switches and relays located on the deployer, without passing through computer or software functional elements.

Also included are four numerical displays, showing critical parameters such as tether length and deployment rate.

This is the only TSS-peculiar equipment located on the aft flight deck.

CONTROL CONSOLE



GROUND SUPPORT EQUIPMENT

Composite listing of TSS system-level GSE includes both factory and field testing equipment.

Insofar as possible field testing equipment and functional testing, with the exception of deployment tests, will be identical to that used in system-level factory testing.

GROUND SUPPORT EQUIPMENT AND FIXTURES - SYSTEM LEVEL

- CONTROL CONSOLE - DEPLOYER AND SATELLITE - FORMATS COMMANDS DECOMS DATA, PERFORMS CALIBRATION AND STATUS CHECKS (SIMULATES SPACELAB DATA INTERFACE)
- SERVO CONTROLLED TETHER REELER - SIMULATES TETHER TENSION AND REELING RATES*
- D.C. POWER CONVERTER, BATTERY CHARGER AND CONDITIONER. (SIMULATES SPACELAB/ORBITER POWER INTERFACE.
- GRAVITY COMPENSATION FIXTURE - BOOM DEPLOYMENT AND SEPARATION TESTING*
- GRAVITY COMPENSATION FIXTURE - SATELLITE SEPARATION, DOCKING, AND CAPTURE*
- ENVIRONMENTAL TEST ATTACHMENT FIXTURES FOR SATELLITE, DEPLOYER, AND AIRBORNE SUPPORT EQUIPMENT FOR VIBRATION, THERMAL VACUUM, ACCOUSTIC TESTING, MODAL SURVEY AND MAGNETIC SURVEY(SATELLITE ONLY)*
- HANDLING DOLLIES, LIFTING SLINGS, FOR SATELLITE, DEPLOYER
- ENVIRONMENTALLY CONDITIONED TRANSTAINERS FOR SATELLITE, DEPLOYER AND AIRBORNE SUPPORT EQUIPMENT.

*FACTORY TESTS ONLY

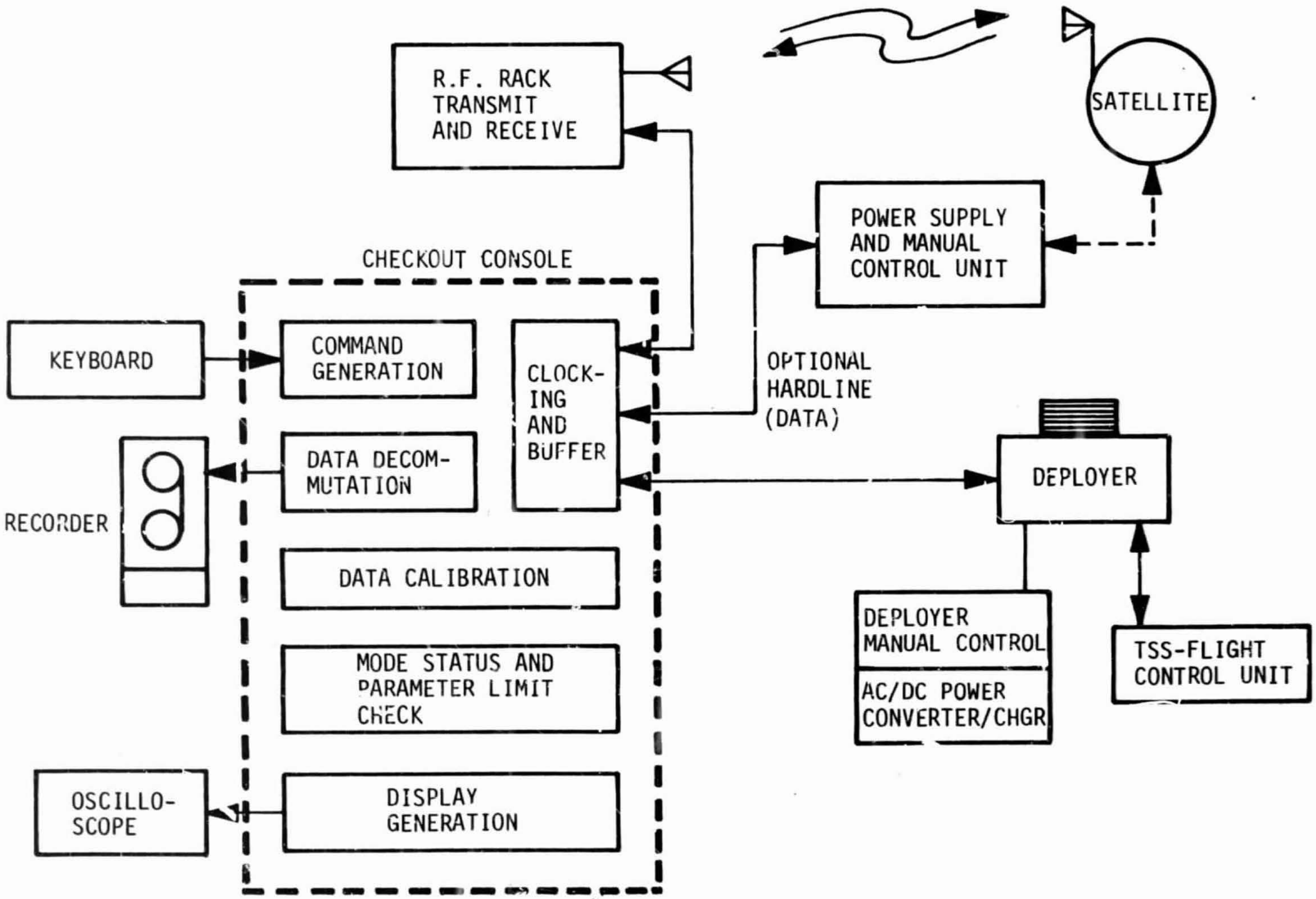
The TSS system test GSE simulates the orbiter interface and performs all functions such as command execution and data handling, directly related to functional testing of the satellite and deployer.

For tests involving open-link R.F. communication with the satellite, the test equipment compliment is augmented with the R.F. Rack.

Small manual-controllers with associated power supply units, enable rudimentary control of both deployer and satellite electrical systems.

A checkout console with functions shown, was constructed and used by BASD on the P78-1 satellite program.

SYSTEM TEST GROUND SUPPORT EQUIPMENT



SOFTWARE

Software functions have been assigned where possible to locations (orbiter, spacelab, deployer) so that maximum advantage is taken of planned orbiter and spacelab software/hardware capability.

Also the resulting functional assignment enables the deployer functions such as tether reeling and tension control to be factory tested with actual hardware/software to be flown.

SOFTWARE FUNCTIONAL REQUIREMENTS

- ORBITER GENERAL-PURPOSE COMPUTER - AVIONICS BAY
  - COMPUTE SATELLITE POSITION RELATIVE TO ORBITER (USING DATA FROM ON-BOARD TRACKING EQUIPMENT)
  - COMPUTE SATELLITE ALTITUDE
  - CALIBRATE SATELLITE HOUSEKEEPING DATA & DISPLAY ON ORBITER DATA DISPLAY (DDU) - AFT FLT DECK
  - FORMAT EXECUTE SATELLITE COMMANDS GENERATED AT DDU KEYBOARD, OR AT GROUND TRACKING STATION
  - MULTIPLEX DEPLOYER & SATELLITE DATA FOR TRANSMISSION ON ORBITER DOWNLINK
  - MONITOR MASTER CAUTION & WARN STATUS - TSS DEPLOYER

SOFTWARE FUNCTIONAL REQUIREMENTS (CONT'D)

- SPACELAB EXPERIMENT COMPUTER - IGLOO - FORWARD PALLET
  - CALIBRATE DEPLOYER HOUSEKEEPING DATA & DISPLAY ON SPACELAB DISPLAY SYSTEM - DDS (AFT FLIGHT DECK)
  - MONITOR & DISPLAY DEPLOYER MODE STATUS
  - FORMAT & EXECUTE DEPLOYER COMMANDS ORIGINATING AT DDS - KEYBOARD
  - GENERATE GRAPHIC DISPLAY (CRT), OF DEPLOYMENT HISTORY - SATELLITE POSITION RELATIVE TO ORBITER

SOFTWARE FUNCTIONAL REQUIREMENTS (CONT'D)

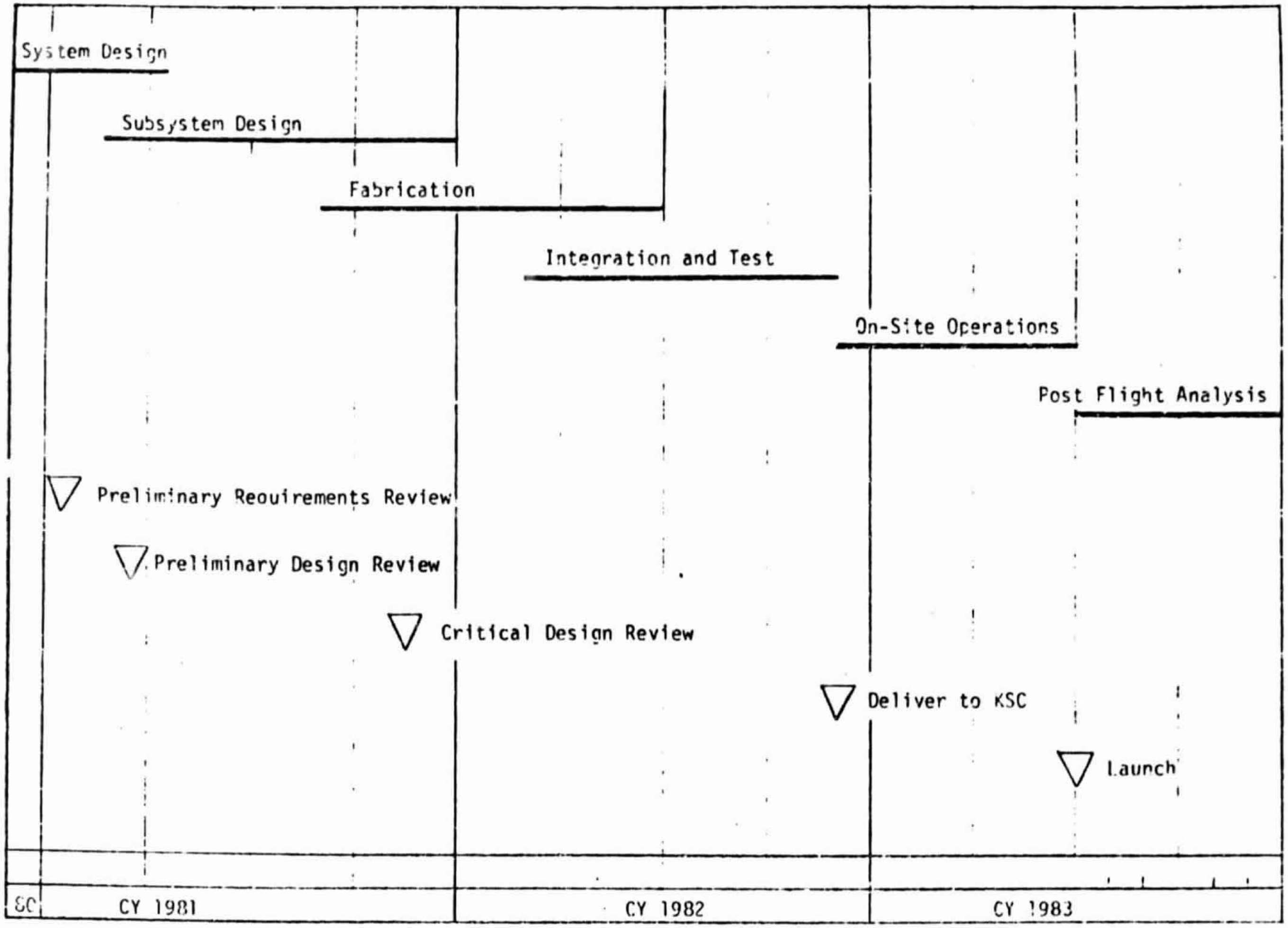
- TSS DEPLOYER CONTROL PROCESSOR
  - TETHER TENSION SERVO - PROBABLY FACTORY PROGRAMMED
  - REEL CONTROL SERVO - DIGITAL/ANALOG HYBIRD - FACTORY PROGRAMMED
  - TETHER CONTROL PROFILE GENERATION - START, STOP, RETRIEVAL, PAYOUT, LENGTH vs. TIME
  - TETHER TENSION CONTROL LAW ALGORITHM

PROGRAMMATICS

The Program Schedule and major milestones displayed represent a reasonable work pace that is consistent with BASD experience on other NASA and Air Force space programs. The twenty-four month time span from program start to hardware delivery represents a readily achievable goal for the nature of the hardware involved. The seven-month period of activities at KSC prior to launch is based on the schedule projected for the four levels of Spacelab integration when part of this activity was to be performed at NASA/MSFC. Performance of all Spacelab physical integration activities at KSC is not expected to have a major impact on the Phase C/D contractors costs as long as (1) operating procedures and contractor involvement do not change significantly, and (2) the time span for Spacelab integration stays about the same. The post-flight support period of six months is somewhat arbitrary, and associated costs may be readily adjusted since this is a manpower level-of-effort period.

As long as the duration of the elements of the schedule and the total span time remain the same, calendar dates may be readily changed for planning purposes, without affecting the time-spread or total cost of the program. However, extensions or contractions of the schedule will influence the projected task man-loadings in a "not-simple" fashion. As a result, only minor scalings of the schedule (and total costs) are possible without considerable review of the individual cost elements.

PHASE C/D SCHEDULE AND MILESTONES



ORIGINAL PAGE IS OF POOR QUALITY

TSS test program is based on a "proto-flight" concept wherein all components are qualification tested unless qualified by alternate methods. Selected component qualification tests are run after integration into higher assemblies.

Parallel test programs are conducted on the satellite and deployer as individual systems, at qualification environmental levels.

The satellite and deployer are functionally tested as a system and undergo joint launch-status environmental testing (accoustic and shock tests).

These are followed by refurbishment and a final functional test before shipment to the spacelab integration site.

OVERALL COMPONENT TEST PHILOSOPHY

- ALL COMPONENTS WILL BE QUALIFIED BY ONE OR COMBINATION OF THE FOLLOWING METHODS:
  - SIMILARITY WITH COMPONENT HAVING PASSED QUALIFICATION TESTS WITH EQUIVALENT OR MORE SEVERE LEVELS
  - ANALYSIS - USED ONLY WHEN DESIGN MARGINS ARE EXTREMELY LARGE COMPARED TO ANALYTICAL ERRORS, OR PERFORMANCE IS NON CRITICAL TO MISSION.
  - TEST AT LEVELS EXCEEDING EXPECTED FLIGHT LEVELS
- ALL FLIGHT COMPONENTS WILL UNDERGO TESTS AT EXPECTED FLIGHT LEVELS, INCLUDING REFURBISHED UNITS.
- QUALIFICATION UNITS MAY BE REFURBISHED, ACCEPTANCE TESTED AND DESIGNATED FOR FLIGHT USE.

COMPONENT TESTING

	QUAL. TEST	ACCEPTANCE	SYSTEM LEVEL
THERMAL VACUUM/CYCLING	X	X	
RANDOM VIBRATION	X	X	
SINUSOIDAL VIBRATION	X		
ACOUSTIC VIBRATION		*	X
SHOCK			X
PRESSURE	X	X	
LEAKAGE	X	X	
VENTING	X		
LINEAR/ANG. ACCELERATION	SENSITIVE UNITS		
EMI - EMISSIONS	X		X
- SUSCEPTIBILITY	X		X
PHYSICAL INSPECTION	X	X	
FUNCTIONAL TESTING	X	X	

*OPTIONAL IN LIEU OF RANDOM VIBRATION

SYSTEM - LEVEL (FACTORY) DEVELOPMENT TESTS AND DEMONSTRATIONS

- ANTENNA PATTERNS TESTS - USING SCALE MODELS
  - SPACECRAFT IN DEPLOYED CONFIGURATION
  - PALLET-MOUNTED R.F. SYSTEMS (IF USED)
- STRUCTURAL MODAL SURVEY - FULL SCALE STRUCTURAL MODELS
  - PALLET-MOUNTED EQUIPMENT IN STOWED CONFIGURATION
  - MAY USE ANALYTICAL METHODS TO EVALUATE PALLET - DEPLOYER RESPONSE
- ACCOUSTIC TESTS - DEPLOYER & SATELLITE IN STOWED CONFIGURATION
  - FUNCTIONAL HARDWARE
- TETHER REELING, CONTROL & PAYOUT TESTS
  - EVALUATES RESPONSE OF SYSTEM TO EXPECTED TETHER TENSIONS PRODUCED BY TEST-FIXTURE REELING MECHANISM.
- BOOM DEPLOYMENT, STOWING & BACKUP SEPARATION.
  - GRAVITY COMPENSATED
- SATELLITE RELEASE, DEPLOYMENT, DOCKING & CAPTURE
  - GRAVITY COMPENSATED, TWO DIMENSIONAL

SATELLITE FACTORY INTEGRATION AND TEST SEQUENCE

SPACECRAFT INTEGRATION → INTEGRATED SYST. TEST → INTEGRATE EXPERIMENTS → THERMAL VACUUM → TO TSS INTEG. SYST. TESTS. (FACTORY)

SPACECRAFT INTEGRATION
- SUB-SYST. INSTALLATION
- SUB-SYST. FUNCT. & I/F C/O

INTEGRATED SYST. TEST
- VERIFY EXP. INTERFACES
- T/M CALIB.
- FUNCT. PERF. CHKS. (S/S).

INTEGRATE EXPERIMENTS
- FUNCT. PERF. ALL MODES
- EMI EVAL.
- MAG SURVEY
- MASS PROP. MEAS.

THERMAL VACUUM
- TEMP EXTREMES
- THERMAL BALANCE

Ball

DEPLOYER FACTORY INTEGRATION & TEST SEQUENCE

DEPLOYER ASSY INTEG. → INTEG. SYST. TEST → THERMAL VACUUM → FUNCTIONAL TESTS → TO TSS INTEGRATED SYSTEM TESTS (FACTORY)

DEPLOYER ASSY INTEG.

- STRUCTURE & BRACKETRY
- PLUMBING & HARNESS
- REELING SYST. & BOOM

INTEG. SYST. TEST

- T/M CALIB
- CAUT. & WARN C/O
- EMC SURVEY
- MASS PROP.
- BOOM DEPLOY/ RETRACT
- REELING TESTS

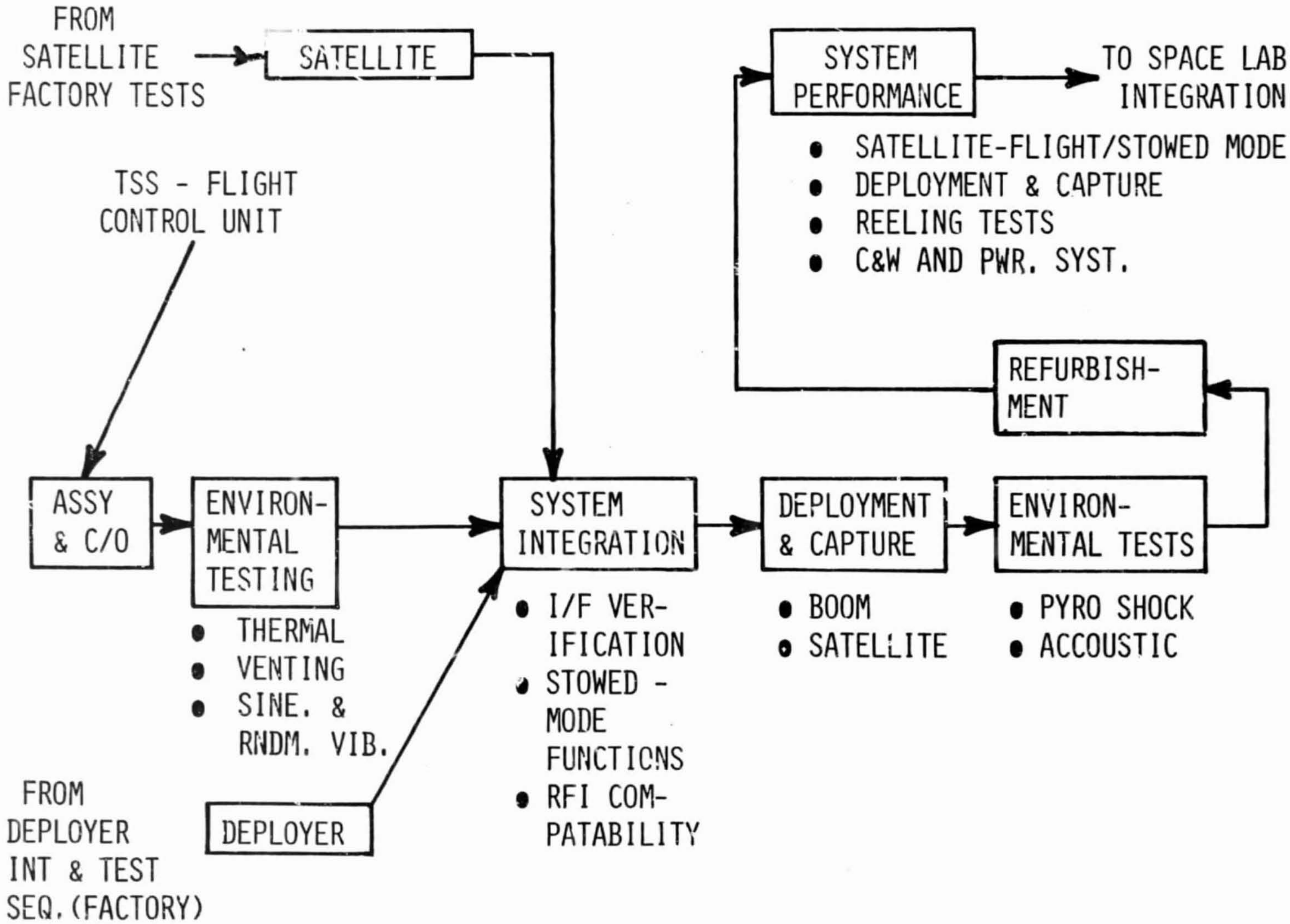
THERMAL VACUUM

- THERMAL EXTREMES
- THERMAL BALANCE
- STOWED FUNCTIONAL TESTS

FUNCTIONAL TESTS

- REELING TESTS

TSS INTEGRATED SYSTEM TESTS - FACTORY



Hazards 1, 2, and 3 require jettison of payload equipment to allow Orbiter entry. The jettison system must be completely dependable. Hazards 4 and 5 require high assurance of avoidance since each could damage the Orbiter making entry impossible. Hazard 7 requires high assurance of avoidance and requires EVA backup to assure entry is not jeopardized.

Most, if not all, of the other hazards identified to date can be controlled by meeting requirements of existing specifications, using good space system design practices, using flight proved hardware and techniques, and assuring that human engineering and crew training are properly accomplished. The TSS presents no hazards not already being addressed by other potential or assigned payload groups, and in fact is less hazardous than many potential payloads which incorporate propulsion units, high pressure systems, high temperature systems, or cryogenic systems. It is anticipated, therefore, that the TSS can be designed to be a safe STS payload without extraordinary effort (cost) to control hazards.

SAFETY DESIGN CONSIDERATIONS

1. FAILURE OF THE REEL SYSTEM TO RETRIEVE THE SATELLITE
2. FAILURE OF THE DOCKING MECHANISM TO LATCH THE SATELLITE
3. FAILURE OF THE BOOM SYSTEM TO STOW THE SATELLITE
4. INADVERTENT RELEASE OR JETTISON OF THE BOOM OR THE SATELLITE WITH THE BAY DOORS CLOSED
5. IMPROPER SATELLITE RETRIEVAL CAUSING A THREAT OF IMPACTING THE ORBITER
6. SUDDEN CATASTROPHIC FAILURE OF THE REELING SYSTEM CAUSING IT TO COME APART IN THE BAY
7. TETHER TANGLED IN BAY EQUIPMENT

STATUS OF DEVELOPMENT

- LARGER FOOTPRINT DIAMETER BOOM THAT HAS BEEN DEVELOPED (BUT OF SAME TYPE ALREADY DEVELOPED).
- LARGER TORQUE MOTORS THAN HAVE BEEN FLOWN (EXIST IS COMMERCIAL VERSIONS).
- REELING MECHANISMS WHICH HAVE NOT BEEN DEVELOPED (BUT ARE SIMILAR TO COMMERCIAL APPLICATIONS).
- TETHER(S) WHICH HAS NOT BEEN FLOWN (BUT OF TYPES USED COMMERCIALLY).
- TETHER CONTROL LAW(S) HAS NOT BEEN DEVELOPED AND MECHANIZED (BUT CAN BE MECHANIZED WITH STANDARD APPROACH).
- THERMAL SHELL FOR CONTINUOUS LOW ALTITUDE SATELLITE OPERATION HAS NOT BEEN DEVELOPED (BUT CONCEPTS HAVE BEEN IMPLEMENTED).